Resources, Conservation & Recycling 183 (2022) 106350

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Review

The circular economy in China: Achievements, challenges and potential implications for decarbonisation

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ARTICLE INFO

Keywords:
Circular economy
Climate change
Carbon neutrality
Policy development
China
Systematic review

ABSTRACT

China's wide-ranging circular economy (CE) efforts have been studied multiple times from a range of perspectives. Synthesizing the relevant literature, this paper provides a critical reflection on the transition to a CE in China. Key factors for China's success in shifting towards a CE are seen in multi-level indicators and upscaling niches. This paper makes a novel contribution on limitations to progress, based on emerging evidence on CE projects that fail to sustain. Enriched by experts feedback, this paper critically addresses future challenges to a deep transition resulting from implementation gaps between early majorities and mass markets and coordination challenges arising through regional and sectoral differences. In light of China's commitments to climate neutrality by 2060, such challenges are considered serious. Based on feasible policy learning, the paper however proposes synergies between the CE and decarbonisation driven by efficiency improvements, comprehensive core indicators, upscaling and urban policies as trigger for deeper transformations. Finally the paper undertakes broader reflections and an outlook on evidence-orientated policy learning for a CE and decarbonisation in China.

Specifications table

Subject Area	Environmental Science
More specific subject area	*Policy Analysis*
Method name	Systematic review process, focus group
Name and reference of original method	*Tranfield, D., Denyer, D. and Smart, P. (2003) 'Towards a methodology for developing evidence-informed management knowledge by means of systematic review', British journal of management, 14(3), pp. 207–222.*
Resource availability	*If applicable, include links to resources necessary to reproduce the method (e.g. data, software, hardware, reagent)*

1. Introduction

China is a major geopolitical player and about to become the largest economy of the world. Over the past twenty years, China has developed wide-ranging ambitions for the Circular Economy (CE) and has been pursuing comprehensive CE policies. In 2020, China announced the target of hitting the peak of carbon emission before 2030 and reaching carbon neutrality by 2060. In doing so, China is amongst the first emerging economies pledging such target and in policy alignment with commitments made by the EU, the UK, the US, and others. The Chinese announcement comes at a time when the country is seen as a large polluter of the world, certainly in terms of greenhouse gas emissions. Despite global competition and geopolitical tensions, however, China and USA have issued a joint pledge to ramp up cooperation in tackling climate change in the run-up to the Glasgow climate conference (COP26) in late 2021 recalling their agreement on reducing emissions in late 2014 that helped to pave the Paris Agreement. China and the EU have a comparable partnership on climate change and signed a Memorandum of Understanding on cooperation on a circular economy in 2019. This all indicates a political space to collaborate in which this article will navigate its analysis on China.

In fact, China has a long tradition and wider ambitions in terms of the CE and an 'ecological civilisation', i.e. the Chinese Communist Party's long-term vision of a harmonious sustainable development (Geng et al., 2016). Some management scholars even consider China as a driver of a green global shift, with other emerging economies to follow, and altogether powering a sixth wave of eco-innovation (Mathews and Tan, 2016; Mathews, 2017). It follows that the relevance of China can hardly be underestimated given it also plays a pivotal role in the global supply

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https://doi.org/10.1016/j.resconrec.2022.106350
Received 5 December 2021; Received in revised form 4 April 2022; Accepted 8 April 2022
Available online 20 April 2022

chains; understanding the speed and depth of transitions in China towards both the CE and net-zero carbon are ultimately a research frontier.

Understanding policies *within* China matters. Since 2000, China has developed many policies and regulations in relation to CE (Yuan et al., 2020) carried out at three levels: micro, meso and macro (Geng and Doberstein, 2008; Su et al., 2013) referring to the firm-level, inter-firm relations and eco-industrial parks (EIPs), and the level of eco-cities, provinces, and regions. Multi-level policies in China are typically developed and implemented through a top-down approach, from the central government to provinces, cities, and factories through setting targets, creating indicators for different industries, and experimenting with various pilots (Geng et al., 2013; Hong and Gasparatos, 2020; Zhao, 2020). Reflecting on those multi-level policies within China, therefore, constitutes the scope of our research.

Studies have evaluated the outcome of CE policies in China, demonstrating achievements in broader environmental goals such as mitigating pollution (Li et al., 2020), biodiversity loss (Ali et al., 2018), resource depletion, greenhouse gas emissions (Liu et al., 2018) and other environmental impacts of climate change (Zhu et al., 2010; Kennedy et al., 2016; Wang et al., 2021). Our paper is adding another outcome by observing a doubling of resource productivity, i.e. the ratio between gross domestic product (GDP) and resource use, since the 1990s (with details in Section 3.3).

The scope of our paper requires furthermore investigating into policy drivers and limitations; it seeks to understand policy challenges and potential systemic failures. Many CE projects seem to struggle, especially the industrial symbiosis projects in the EIPs (Huang, 2020). Factors this paper addresses are implementation gaps, distorted incentive systems, and coordination challenges. Despite obvious relevance and slowly growing research interests in this area, little is known about the underlying factors for success and failure of the CE policy development and implementation in China, and it is unclear how CE in China interacts with decarbonisation and could contribute to the carbon neutrality target. Addressing this gap is a key objective of this paper.

This paper therefore aims to analyse underlying success factors *and* limitations of the CE policy development and implementation in China as well as potential synergies with carbon neutrality ambitions. It makes novel contributions on key success factors, limitations and challenges; seing China at a crossroads, the paper also explores potential synergies between CE and decarbonisation in manufacturing. The research questions are as follows:

- How have CE policies been evolving in China and what are the main features?
- What are the main success factors and challenges of implementing CE in China?
- How do both success features and challenges relate to manufacturing decarbonisation strategies?

In terms of methodology, this paper has developed the research questions based on a synthesis of relevant academic papers and policy documents in relation to CE in China; furthermore, a focus group was organised to collect insights from fourteen experts regarding the success and failures of the CE in China as well as its implications for decarbonisation. Doing so allows us to present a critical review of the literature that emerges organically from identifying the importance of the topic and synthesizing the literature. Clarifying such scope, this paper does not aim at a comparison with other countries (see e.g. for a comparison with the EU McDowall et al. 2017), nor do we seek to provide an overview on the CE in general (see here e.g. Kirchherr et al., 2017; Korhonen et al., 2018; Hartley et al., 2020, Lieder & Raschid 2016, Geng et al. 2019). It should be mentioned that our team of authors is both interdisciplinary and international with credentials on the topic areas, thereby providing a capability to reflect from different angles. Indeed, the authors hope to stimulate further debates.

This paper is structured as follows. First, the process of the method used in this research is introduced, with details provided in supplement information a descriptive analysis of the literature and CE policies in China is provided, with a particular focus on recent findings. Third, the findings and answers to the analytical research questions on achievements and challenges are presented, followed by a discussion of the implications for carbon neutrality.

2. Research methods

Studies addressing China are facing methodological challenges in comparison to comparative policy assessments in OECD countries. Survey data, such as the EU's Community Innovation Survey or the EU flash barometer, does not exist or is hardly accessible for foreign scholars. The political system of China and its policy style differ significantly from OECD countries, for which a vast amount of research has been done; however numerous scholars have been working on China and its CE attempts and given evidence on successful outcomes and limitations based on a range of methods, including industrial ecology and material flow analysis. This study provides an original analysis based on a critical review of the academic papers and policies related to CE in China. Throughout applying this methodology, we could sharpen our research questions and scope by learning from a variety of papers using other methods such as bibliometric analysis, input-output analysis, and individual case studies. There also has been a focus group with experts in those topics, as evidenced through the acknowledgements, together with the long-standing expertise of the authors. This mixed method can address the underlying factors of the achievements and limitations of CE policy development and implementation in China and help preparing future pathways on a CE and carbon neutrality for the Chinese economy.

The methodological approach follows procedures to conduct the review of literature and policies (Tranfield et al., 2003) as well as a focus group (Kitzinger, 1995) to collect insights from experts and validate the findings. In combination this allows for a critical analysis of main success factors and limitation and an evidence-orientated outlook on the interrelation between the CE and decarbonisation. Fig. 1 describes the research framework. In the interest of being concise, our analysis of Phase 1 'Systematic review of literature and policies' is provided in the supplement information to our paper.

In relation to phase 2 of Fig. 1, the lead authors of this paper decided to set up a focus group to address the research questions. Previous literature on main features, drivers, and limitations of the CE in China is just emerging; especially findings on challenges are hard to validate, given formal evaluations are yet emerging for a few areas and results go into the qualitative realm of institutional capabilities in the Chinese context. To the extent possible the authors have been incorporating such analysis on China and applied for the topic of this paper. As an additional step, the authors have been reaching out to fourteen experts to form a focus group to discuss the preliminary findings and obtain further insights and evidence. The advantage of adopting such focus group method is that it provides a participative form of enquiry where the different perspectives of experts can be gathered to study the problems (Kitzinger, 1995). The experts were selected based on their previous publications in this field, both with Chinese affiliations and others. We shared our intention and a draft paper prior to a focus group workshop which was conducted online on 22 September 2021. The workshop was divided into two parts. The first part was focused on commenting the success and failure of CE in China, and the second part was an explorative discussion on the implication of CE to decarbonisation. The feedback during the workshop has been recorded; experts had the opportunity to give written feedback after the workshop. As a result, some participants with significant contributions have become co-authors of this publication as noted at the end of this paper. All participants are named in our acknowledgements.

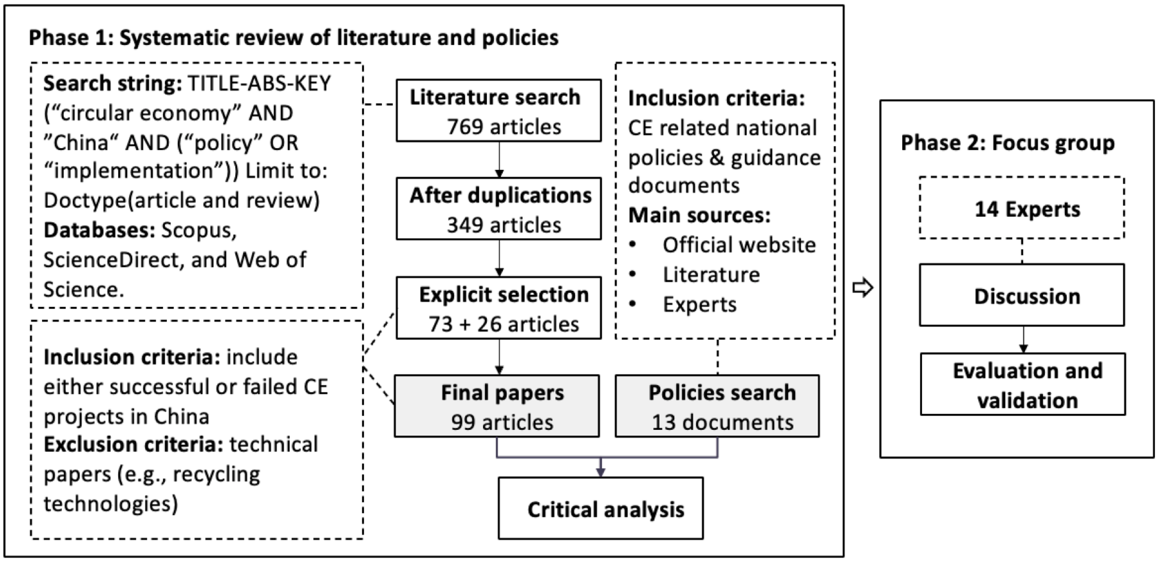

Fig. 1. Research framework.

3. The development of the circular economy in China

This section identifies the scope of CE development in China based on the systematic literature survey; it starts with the policy development of the Chinese version of the concept itself (3.1) and continues with the institutional setting (3.2). Synthesizing the literarture this section adds findings on the outcomes of the CE in China in relation to resource productivity (3.3) and on resource security as an underlying driver (3.4).

3.1. The evolving understanding of the CE concept and policies in China

The concept of CE was formally accepted in China in the year 2002 after more than ten years of rapid development and socio-economic success and realising environmental challenges with discussions about cleaner production. Since then, the understanding of CE in China has evolved over time. We identified the major policy documents across the main stages of the CE development in China from 2005 to 2017 (details listed in Table 1 in Appendix). The timeline and the categories of guidance documents, industrial policy, finance policy, tax policy, and investment policy demonstrate a long policy evolution of CE policy in China and its embeddedness in broader policies of growth and development. A number of documents (e.g., 'suggestions', 'opinions', 'notice') are aspirational, perhaps comparable to White Papers, and give guidance about future directions rather than being legally binding or having immediate financial implications for main actors. This is part of the policy style in China with elements of 'command and control' and 'top-down' as well as flexibility at the level of provinces and local authorities (McDowall et al., 2017).

In 2005, the State Council issued *"Opinions on accelerating the development of circular economy"*, proposing a policy frame, basic principles, main objectives, key tasks, and policy measures to promote a CE. This document is widely considered as the first relevant policy document, indicating the policy direction with a huge impact on the subsequent CE development in China (Geng and Doberstein, 2008; McDowall et al., 2017). It has been the starting point to implement a CE in China within the 11th Five-Year Plans starting from 2006. The *Circular Economy Promotion Law* was subsequently published in 2008, being effective in 2009, with a focus on 3R strategies (i.e., reduce, reuse, recycle). This is the first policy document with the term 'circular economy' and was widely regarded as an influential national guideline on implementing CE in China (Geng et al., 2012).

The understanding of the CE concept in China is broader compared to the EU (McDowall et al. 2017). China started to cope with environmental challenges resulting from its rapid industrialisation and developed the CE as a holistic approach seeking to align environment and development; it therefore covers a range of economic, environmental and social indicators. It adopted 3R policy lessons both from Japan and from several European countries as well as from industrial ecology. In comparison, the EU had a strong uptake in 2015 with the adoption of the Circular Economy Action Plan and in more recent years (European Commission, 2015); while the EU focusses more on the waste hierarchy and product policies (Domenech and Bahn-Walkowiak 2019; Hartley et al., 2020), China has been grappling with a range of issues including water pollution and air pollutants.

The interpretation of the CE concept in China has evolved over time (Geng et al., 2013). The earlier CE related policies based on the Circular Economy Promotion Law (2008) were focused on the improvement of resource productivity, with particular focus on energy, as the Chinese industrial systems were largely dependant on energy- and resource-intensive production systems. The later policies, evidenced through the Revised Indicators of the Circular Economy Promotion Law (2017) emphasized stronger the circularity of industrial systems, after significant improvement in resource and energy efficiency. The 13th Five Year Plan (2016–2020) validates the importance of CE as a national policy and as a fundamental pillar of the economy. The *Circular Development Leading Action Plan*, released in 2016 by National Development and Reform Commission (NDRC), aims to address drivers of environmental and social externalities and stresses opportunities in new digital solutions. It also aims to influence the broader value chain by highlighting the potential to integrate CE principles at the design stage of products, and opportunities to develop new CE business models in the future. In 2018, the *Circular Economy Promotion Law* (first published in 2008) was revised and updated. Afterwards the 18th Communist Part of China (CPC) National Congress prompted the position of CE to a new strategic level by making the establishment of a full-fledged resource recycling system as one of the goals of building a moderately prosperous society in an all-round way by 2020. The 'dual circulation' (domestic-international circulation) was proposed in 2020 as a national strategy to reorient China's economy by prioritising the internal circulation (e.g., domestic consumption). This is partly due to the instability of international trade and has evolved out of the traditional CE strategy (see chapter 3.4 below). The recent 14th Five Year Plan on circular economy (2021–2025) continues to promote resource conservation and recycling in China by setting targets and help ensure national resource security, and more importantly, it clearly emphasises it as an approach to tackle climate change and achieve carbon neutrality by 2060 (see box below).

Box: CE Targets in the 14th Five Years Plan

- Increasing resource productivity by 20 percent compared to 2020 levels.
- Reducing energy consumption and water consumption per unit of GDP by 13.5 percent and 16 percent, respectively, compared to 2020 levels.
- Reaching a utilization rate of 86 percent for crop stalks, 60 percent for bulk solid waste, and 60 percent for construction waste.
- Utilizing 60 million tons of waste paper and 320 million tons of scrap steel.
- Producing 20 million tons of recycled non-ferrous metals.
- Increasing the output value of the resource recycling industry to RMB 5 trillion (US$773 billion).
- Building a resource recycling industry system and improving resource utilization efficiency
- Building a recycling system for waste materials and fostering a recycling-orientated society
- Deepening the development of the agricultural circular economy and establishing circular agricultural production
- Source: China Briefing 16 July 2021, accessible here (21 Sep 2021)

3.2. *The institutional setting and operational framework of CE in China*

Traditionally, the Chinese central government and the National People's Congress play a leading role for the national governance. Besides, there is a strong horizontal coordination amongst ministries and agencies, as well as a strong vertical coordination between the central government and the provincial governments. However, policy coordination challenges still exist for its low carbon regulatory policy (Zhang and Andrews-Speed, 2020).

Fig. 2 depicts the institutional structure and operational framework of China's CE implementation with agencies and policies and the level of policymaking involved.

CE policy shift. Several ministries have been involved in CE policy making. The National Development and Reform Commission (NDRC) is the leading CE agency through developing basic CE regulations, while the Ministry of Industry and Information Technology is in charge with competences related to resource recovery and product development (including Extended Producer Responsibility, EPR); the Ministry of Environment and Ecology develops relevant standards and overlooks the programme on EIPs. Before 2004, the Ministry of Environment and Ecology was responsible for CE related policies, while in 2004, the NDRC took over the responsibility of promoting CE. This change indicates that CE was no longer only regarded as an environmental policy, but more a comprehensive development policy. It also indicates that 'economy' is considered as the core of the policy, and that circular activities follow economic purposes.

Financial leverage matters. The Ministry of Finance and the NDRC have been setting up a special fund for key projects as noted in the *Interim Measures for The Management of Special Funds for Circular Economy Development* in 2012. This special fund mainly concentrates on action areas of urban mineral resources (such as electronic wastes, waste plastics, construction waste, etc.), kitchen waste utilization and their harmless treatment, industrial parks and transforming recycling, remanufacturing, clean production technology, etc. The state has invested more than 10 billion yuan, and it is estimated to have driven social investment of more than 100 billion yuan.

Education facilitates CE promotion. In line with a general emphasis on education, the NDRC, the Ministry of Education, the Ministry of Finance and the National Tourism Administration have jointly established the national CE education demonstration bases in 2012 and has been running education campaigns on a CE since then.

3.3. *Outcome of CE policy and implementation in China*

The comprehensive and ambitious CE policies in China and their scope yielded measurable outcomes in resource productivity, i.e. relative decoupling of resource use from GDP growth, as well as in circularity.

Increasing resource productivity. Our data analysis shows a remarkable success of decoupling GDP from resource use in China over the last twenty years, a strong relative decoupling leading to a doubling of resource productivity in China and much different to e.g., the EU, as is shown in Fig. 3.

Source: self-development. In line with Eurostat and UNEP's

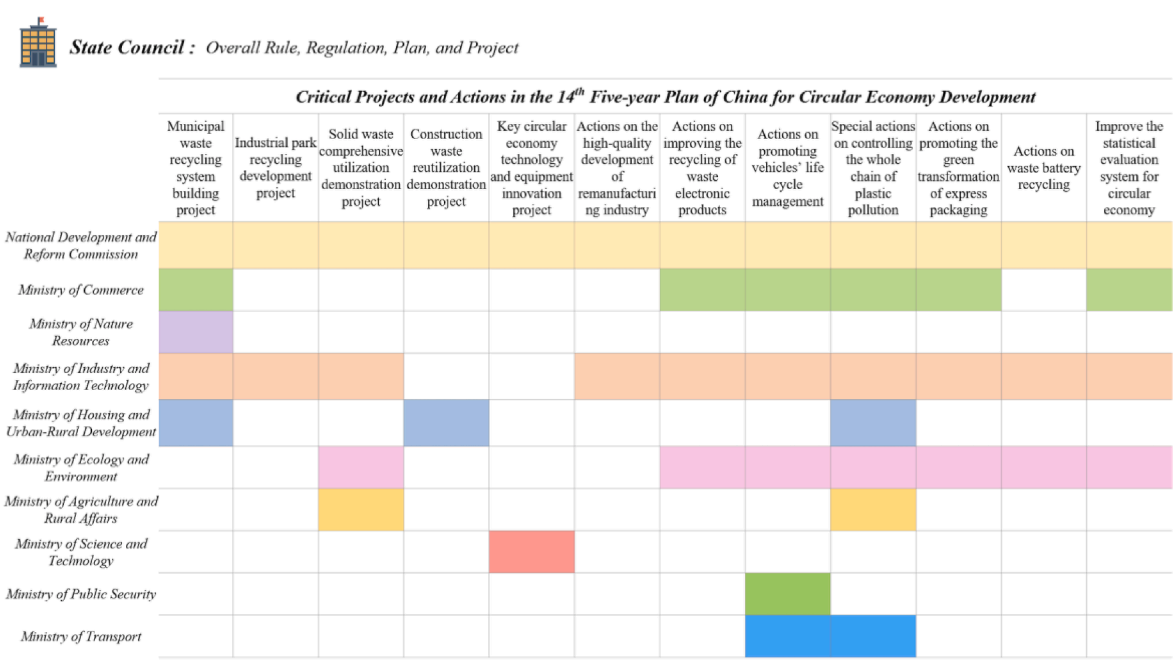

Fig. 2. The operational framework of China's circular economy
Source: own development done by Beijia HUANG and Xiaozhen XU.

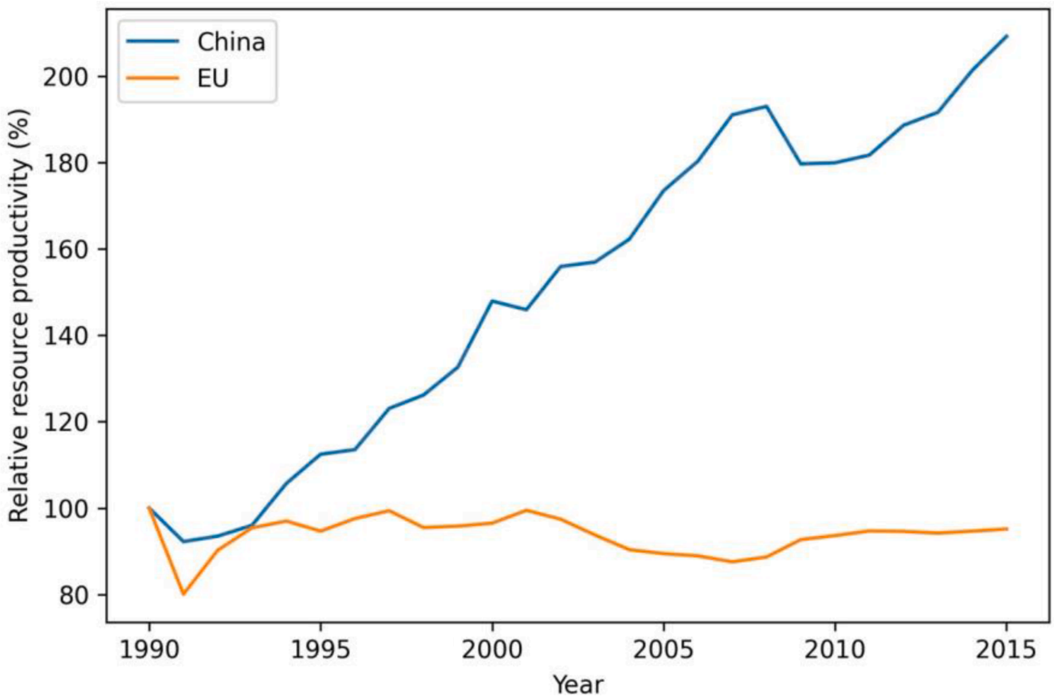

Fig. 3. Increases in resource productivity in China and EU 1990 – 2016.

International Resource Panel (IRP), we define resource productivity as the ratio between gross domestic product (GDP) and resource use. Indicators for resource use are based on Economy-wide material flow accounts (EW-MFA), which include compilations of the overall material inputs into national economy, the changes of material stock within the economy and the material outputs to other economies or to the environment. Resource use is measured as 'Material Footprints', accounting for domestic material consumption plus the full upstream material requirements with most recent data from the UNEP IRP database; GDP data from World Bank measured in US $. The term Material Footprint is seemingly used interchangeably with the term Raw Material Consumption (RMC) and is commonly considered more comprehensive than the indicator 'Domestic Material Consumption' (DMC) which doesn't cover upstream material requirements.

Data should, however, be interpreted with care. The absolute numbers show an increase in resource use in China, and a resource productivity ratio that is converging to EU numbers, yet it is still higher, i.e., the Chinese economy is less resource productive than the EU in absolute numbers. A main driver for relative decoupling in China has been GDP growth. Other factors ought to be mentioned too, such as an upgrading of the entire capital stock, a servitization of the economy, and the increase in relative commodity prices from the year 2002 till the financial crisis in 2007/08 and bouncing back again after a short drop till about 2011. One notice is an alignment of material footprint data with CO_2 emissions in China, different to the EU where material footprint data aligns with GDP while CO_2 emissions have been decoupled. This confirms our assumption of resource use being correlated with CO_2 emissions in China and a significant relative decoupling from GDP.

Increasing circularity. A recent paper by Wang et al. (2020) provides an excellent comparison about main material flows in China in 1995 and 2015, demonstrating both the higher volumes in the use of metals, mineral, biomass and fossil fuels in absolute numbers as well as the slow emergence of using more secondary materials. Their findings demonstrate an increase in the domestic extraction of non-metallic minerals as well as increases in the circularity rates from 2.7% to 5.8% for their 'input socio-economic cycling rate' (ISCr), reflecting the increasing share of secondary materials, and increase in the circularity for their 'output socio-economic cycling rate' (OSCr) from 7.2% to 17%, reflecting progress in industrial solid waste management. Their analysis indicates progress in recycling both in absolute and relative numbers that is higher than progress in establishing markets for secondary resources; a trend on which our paper reflects further down below. We also draw attention to our previous historical trend analysis on a possible saturation effect (Bleischwitz et al., 2018) by comparing the demand for materials in China for the last decades with the per capita consumption in UK, USA, Germany, and Japan regarding the use of steel, copper, aluminium and cement. Our tentative conclusions here recognize that a range of drivers is likely to have shaped China's improvement in resource productivity and helped China to start becoming more circular.

3.4. Resource security as an underlying driver for a shift towards CE in China

Policy drivers and structural drivers have been addressed above; here we add resource security as a driver that is often overlooked in the literature. The Chatham House Resource Trade Database reveals relevant patterns of import dependency which can be seen as an underlying driver for shifts towards a CE in China. Due to its enormous growth since 1990s, China's share in international commodity markets has been growing constantly. Its recent share of 18% (2018) in international trade with resource commodities is comparable to the EU. However, trends have been heading upwards for China and downwards for the EU. The EU had a share of 17% in 2000 while China's share in 2000 was just 3.8%. This underlines the growing relevance of China in global manufacturing. China has become world champion in importing commodities with a market value of US $ 806 bn in 2019 (Chatham House Resource Trade Database, 2019), which makes it vulnerable to commodity prices and supply chain disruptions. Measured in physical terms, the volume of commodity imports measured in billion tonnes has been increasing by a factor of ten from 2000 to 2018, with most significant increases in forestry products and minerals and metals.

While China's import dependency is diversified across a range of countries, its export dependency on some resource-rich countries is high: 64% of Australia's exports in minerals and metals go to China, 55% for DRC, 47% for Chile, 41% for Peru. As regards to imports of minerals and metals, there has been a steady increase in mass units from 116 m tonnes in 2000 to 1.3bn tonnes in 2018 with no visible saturation yet; 50% of Chinese imports of minerals and metals come from Australia (2018), followed by Brazil and South Africa; more recently, the fastest growth has come from Guinea (111% from 2013 – 2018).

China has a negative commodity trade balance with EU-27. This might come as a surprise given Europe's strategic dependency on the import of critical materials such as Rare Earth Elements (REE). However, Europe exports in particular forestry products, metal products and agricultural goods at large scale to China; the value of EU-27 exports in 2019 has been about $29bn while the value of imports from China has been in the order of $16bn. Both the value and the weight of speciality metal exports from China to EU-27 have been decreasing since 2008, with a low point in 2015 and increasing moderately since (with steeper increases for cobalt, zirconium, titan). This reconfirms that China is a resource-intensive economy with an interest to pursue a circular economy for strategic security reasons too.

4. The main policy features of CE achievements in China

In the process of promoting CE, China has achieved a strong relative decoupling of GDP from using natural resources, as well as from air emissions, water pollution, and solid wastes (UNEP, 2019). Based on our systematic literature survey and validated by our focus group, we identify three policy features that are distinctive to China's efforts on the CE and efforts of upscaling of solutions: multi-level indicators, bridging the gap between demonstration projects and markets, and eco-industrial parks.

4.1. CE indicators in China

China places much emphasis in its CE ambitions on supply chains, on scale and place (McDowall et al., 2017). Accordingly, China has been developing fairly comprehensive CE indicators on different levels: macro, *meso*, and micro; called "three plus one" (Geng et al., 2012; Zhu et al. 2019). The 'three' addresses the macro cycles in society (including provinces), the *meso* cycles in industrial parks, and the micro cycles in enterprises. The "one" involves the waste industry on treatment and resource recovery.

Beyond addressing actors and governance levels, indicators are also important in China as incentive. They form part of the governance system for the promotion of senior officials. Called 'target responsibility system', the career advancement of officials is tied to the performance against targets set in the Five-Year Plans. In this context, the enforcement of regulation is done through evaluation of performance against indicators and less through legal mechanisms. Accordingly, these indicators are detailed and have been subject to a vast amount of analysis and discussion amongst Chinese scholars (McDowall et al., 2017; Geng et al., 2019; Wang et al., 2020).

NDRC had developed the first CE index system in 2007, while the Ministry of Ecology and Environment had developed the first EIP index system in 2006 (Geng et al., 2009). NDRC then released an updated CE index system in January 2017 to assess the implementation of CE in practice and give further guidance. These indicators are based on the Material Flow Analysis (MFA) method and are applicable at all macro-meso-micro levels. The revised system has a more nuanced structure made up of three main interconnected categories:

a) **Comprehensive indicators**: measure the overall productivity of main resources, such as fossil fuels, metals, minerals, and biological resources. They also measure the recycling rate of the main waste streams from agriculture, industries, urban construction, and urban food *etc*.
b) **Specialised indicators**: measure specific streams of resource productivity, waste recycling rates, and the value added by recycling industries.
c) **Supplemental indicators**: focus on the end-of-pipe treatment of waste, such as industrial, solid, and wastewater municipal waste, and the emission of main pollutants.

While the set of indicators is highly sophisticated and technically elaborated, it also comes with flexibility in implementation that will be analysed below. Huang et al. (2019) note a drawback on including an aggregated indicator on materials in their indicator system that would be comparable to 'material footprints' as they are used through the International Resource Panel and international scholars. More broadly, resource productivity is often referred to in policy documents but measured along individual material flow system and still lacks a standardized accounting method in China (Wang et al., 2020). Such a core indicator could be both serving as denominator for progress towards the CE, especially for calculating a rate for re-use and secondary materials comparable to the EU's 'circular material use rate'. It would also be useful for assessing potential trade-offs with other socio-economic indicators and to establish scenarios on future developments beyond the five years planning. Section 5 will analyse implementation gaps and coordination challenges resulting from those limitations.

4.2. Demonstration pilot projects

Since the official approval by the State Council in 2005, the NDRC has been organising two batches of national CE demonstration pilot projects together with relevant departments, bringing CE into the innovation system through Research, Technology & Development (RTD) and bridging the gap between demonstration and market development in regions. 178 units have been selected in key industries such as iron and steel, nonferrous metals, electric power, coal, chemical industry, light industry and building materials. In addition, agricultural and food wastes from private households were addressed.

During the 12th Five Year Plan (2011–2015), China's NDRC synthesized 60 best practices from the pilot projects at enterprise, industrial park, and regional levels (NDRC, Circular Economy best practices). These projects have been examined through an "*Assessment scheme of national circular economy standardization pilot project*", which included four assessment criteria:

1) Operational efficiency mode of a CE,
2) Development of a CE standard,
3) Application and readiness of dissemination of CE standards and
4) Development of a CE standard information platform.

China also started to scale up the demonstration pilot projects within the Development Strategy and by launching the *Immediate CE Action Plan* in 2013. This action plan highlighted the demonstration pilots called "ten, one hundred, one thousand", which means 10 projects, 100 cities and 1000 enterprises (see Table 2 in Appendix). To implement this action, it is critical for the state and local governments to provide additional financial support, while all the relevant enterprises should seek their investment channels.

As a follow-up, the NDRC and the Ministry of Finance in China have issued the *Notice on Typical Experiences of National Circular Economy Demonstration pilot projects*, summarizing experiences and providing guidelines for further promotion (see Table 3 provided in Appendix). It is meant to draw 'lessons learned' within and across those projects and enable further dissemination. For example, the recycling and utilization mode of renewable resources is combined with the concept of "Internet plus", and waste management is combined with options for a public information service platform. As a result, many regions and industries could achieve further uptake of CE projects.

Successful demonstration projects can be transitioned into eco-industrial demonstration parks with national funding. By the end of 2020, China has supported 100 key industrial parks, and promotes 75% of national parks and 50% of provincial parks to carry out a circular transformation.

Subsequently, China has developed approaches for new missions and roadmaps in some key industries and industrial parks at the level of provinces (see Fig. 4). The current 14th Five Year Plan (see box above) will strengthen recycling and markets for secondary resources. Over the next ten to twenty years, the intention is to transition further to new business models and more circular cities through urban industrial symbiosis, combined with material flow analysis and CO_2 reduction (Wang et al., 2020).

The city of Shanghai is at the forefront of efforts of moving towards more circular system at a city level through its recent municipal waste separation schemes (e.g., Shanghai Master Plan 2017–2035), and its active role in the recently established carbon market (Nogrady, 2021). It actively promotes the Chinese Social Credit System for those efforts. Based on these scenarios, the potential of turning waste into energy and the reduction of total energy consumption and CO_2 emissions of Shanghai has been estimated to reach 6.6% and 4.9% (Dong et al., 2018; Xiao et al., 2020).

4.3. Eco-Industrial parks in China

China's economic model places much emphasis on industrial parks as demonstrators and upscaling mechanism (Mathews and Tan, 2016; Mathews et al., 2018). Starting in the 1980s, the Chinese government started setting up Industrial Parks in coastal cities. China is estimated to host 2543 parks in 2019 that produce more than 60% of the national industrial output (Bank, 2019; Zhe et al. 2020). While many of those traditional Industrial Parks are seen as environmentally harmful (Bai et al., 2014; Fan et al., 2017), China has also been establishing Eco-Industrial Parks (EIPs) since 2001 in collaboration with UNEP as key to combine industrial innovation and development with ambitions towards what is now called an ecological civilization. Their development has been accompanied and enabled by various laws and programmes (Geng and Zhao 2009; Huang et al., 2019; Hong and Gasparatos, 2020). In the future, both Industrial Parks and EIPs are likely to play a vital role in circular cities and a more CE industrial system as a whole. Even though EIPs have been implemented in most regions of the world (UNIDO 2016), China is clearly ahead in having implemented EIP initiatives at such a large scale and rapid pace (Liu and Côté, 2017).

Currently, the National Demonstration Eco-Industrial Parks (NDEIPs) programme is most representative. It has a concise set of indicators and performance targets, strong government support and direct involvement, and strict structures and regulations (Geng et al., 2009; Bai et al., 2014; Huang et al., 2019; Hong and Gasparatos, 2020). By the end of 2020, more than 90 Industrial Parks have been included in the NDEIPs work, mostly concentrated in the more developed coastal regions. These NDEIPs concentrate on a rangeb of industries (manufacturing including electronics, equipment, medicine, automobive, materials, food and beverage, chemical products, energy, textiles and clothing, electrical machinery, mechatronics, metal smelting, pulp and paper, environmental technologies, agricultural and food processing, building materials, petrochemical, etc.).

EIPs are usually categorized as (a) integrated (i.e. with entities/operations from several industrial sectors); (b) sectoral (i.e. with a dominant industrial sector and others); and (c) venous (i.e. the dominant industrial sector is waste reuse and recycle) (Hong and Gasparatos, 2020). Alongside with the general CE development, the EIP standards also experienced several rounds of evolution since the 2000s (MEP, 2016). The new EIP standard (HJ/T274–2015) has been implemented since 2016. Although no formal economic impact assessment of those EIPs has been done yet, recent research indicates improvements both on environmental indicators and economic competitiveness of EIPs and a high ranking of EIPs in more general economic indices (Zhihua Zeng et al. 2020).

Challenges of transforming industrial firms, existing industrial parks, and whole industrial structures is increasingly acknowledged (Hong and Gasparatos, 2020). Based on the *Green Manufacturing Standard System Construction Guide* (2016), the *Industrial Green Development Plan (2016–2020)* and the *Green Factory Evaluation General Rules (GB/T 36, 132–2018)*, the NDRC has promulgated a policy in 2020 called *Opinions on Accelerating the Establishment of Green Production and Consumption Regulations and Policy System*. It outlines the direction of green production and consumption regulation and policy system, puts forward related laws, regulations, standards, policy to achieve greener production and consumption systems by 2025 and announces more action in

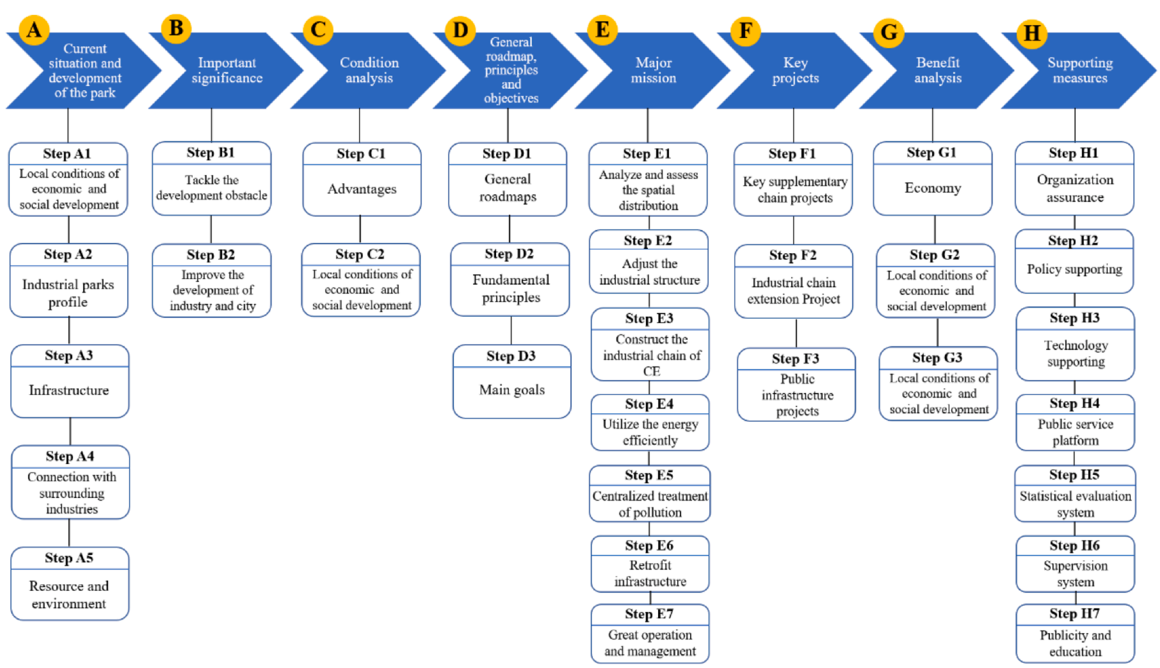

Fig. 4. Procedures to plan for a circular transformation.
Source: Source: own development done by Beijia HUANG and Xiaozhen XU.

nine action fields, including green design, clean production and circular economy, industrial pollution governance, clean energy development, green agriculture, green service, green products, and green living.

To achieve such new direction, a transformation will be needed in various existing parks, especially for traditional industries. Fig. 4 is a novel figure that illustrates the transformation steps towards a more CE system. The key are the steps to develop roadmaps ('D'), create missions ('E'), and define projects to deliver. Although it seems to follow a mission-orientated policy approach (Mazzucato, 2017) and entail elements of a transition management approach (Flottau, 2017), it is less explicit on addressing barriers and path dependencies than those approaches; the following section elaborates on implementation and coordination challenges in China. Fig. 4 also underlines a multi-level governance challenge as EIPs are place-based while industries are parts of national and international supply chains. Thus, it will be highly interesting to study challenges of supply chain standards and new product designs for those market transformations in more detail in the future. The next section will address some of those challenges.

5. Critical insights on the circular economy in China

5.1. Challenges and weaknesses

China has been widely considered as one of the forerunning countries in beginning to implement CE; the achievements in relative decoupling of resource use from GDP, enhanced recycling and increasing circularity have been documented above. It also becomes apparent that the CE in China differs from approaches in the EU through a broader environmental approach, e.g. by also addressing air pollution and water and having less emphasis on the waste hierarchy, as well as through a distinct policy feature on cleaner production at different scales. However, our analysis also seeks to identify policy weaknesses or failures and contribute to assessing China's readiness to cope with a range of future challenges. Doing so should help implement the new five-year plan on a CE in China but in particular address structural issues any CE policy in China and other parts of the world will have do deal with, such as an alignment with decarbonisation requirements. As a starting point for our analysis, we observe an implementation gap between pioneers and transforming majorities as well as coordination challenges across companies, sectors and regions. In our review, Zhu et al. (2019) confirm our view; the recent work done by Pesce et al. (2020) with a CE survey amongst companies in China, as well as Zhang and Andrews-Speed (2020) with a climate policy analysis are useful starting points for such emerging research perspective.

In retrospective, much of the general 'success' in China can be attributed to 'low hanging fruits' of continuous efficiency improvements in production processes (e.g. on metal industry for 2000 – 2015: Chao Feng et al., in press). Most CE implementations in China so far could apply known technologies and tools to improve factories' resource and energy efficiency, based on opportunities to catch-up compared with counterparts in developed countries at that time.

It appears that policy learning in China has mainly been focussing on winners. Although most official documents depict the success of the CE projects in China, more recent studies start indicating that many of these projects have either failed or could not sustain after initial success (Huang, 2020). The authors' case studies in one of the CE demonstration pilot companies, for instance, shows that their CE implementation mainly includes the use of the energy-saving technologies and lean production strategies learnt from their European business partners. These approaches improved the energy and resource efficiency at the level of factories, however, many of those technologies and tools were not as advanced as similar companies in developed countries. In line with our discussion of Fig. 3 and chapter 4 above, factories in the US, Europe, and Japan might have achieved this level of efficiency in 1990s.

Also, the high-tech and export-orientated manufacturing sectors have been more advanced in greening their operations, while sectors like construction, agriculture and others have been lagging. Establishing and boosting new markets for secondary materials has proven to be difficult, even in the advanced 'experimental Special Economic Zone (SEZ)' of Shenzen due to sceptic attitudes towards the quality of recycled construction products (Bao and Lu, 2020).

At *meso* level, many industrial symbiosis projects in EIPs have actually failed. Huang (2020)'s research revealed the failure of CE 49 projects studied in an EIP in China, with a dominant industry in sugar refineries and its related symbiosis industries, such as paper production. This study also revealed the reasons behind these failures, part of which is due to the "top-down" and "government-driven" approach of CE policies in China in combination with path dependency and implementation gaps. The numerous EIPs are primarily located in the Eastern provinces and spur impressive large-scale changes. Other challenges of the effective implementation of EIP projects are identified as the gaps of guidelines and standards of EIPs, the disjoint between EIP planning and implementation, the manipulation of EIP concepts and the lack of comprehensive assessment frameworks (Hong and Gasparatos, 2020).

Uneven progress in EIPs and greening resource-intensive industries reveals a regional inbalance: Western and Northern provinces have deficits in institutional capabilities to absorb pioneering eco-innovations and are lagging behind (Chen and Lin, 2020b, 2020a). This regional implementation gap in China can be explained with the notion of 'experimentation under hierarchy' (Heilmann, 2008). Lessons do get learned – but much of this happens quietly and uneven across provinces. The bonus system for public officials that is aligned with broader macro-economic goals is not yet encouraging transformations in each province; more trade-offs and synergies at the provincial level would need to be evaluated. As a result, some local leaders are seeking for compliance at low levels of ambitions for the CE. They can use the governance space to interpret and implement governmental guidance according to local conditions as a means of balancing local lobby groups, with the result of falling behind or not doing anything at all. A side observation is a dependence on state finance, implying a project would eventually collapse once the government stops the finance support (e.g., subsidies and bank loans). A recent study on solar energy in China sheds light on those contradictions emerging from the central-local interaction in China (Lo and Castán Broto, 2019).

An important element of regional political economy in China is the existence of '*zombie industries*', i.e., resource-intensive industries that were pivotal to develop but now become an obstacle to an ecological civilization. However, those companies are relevant for economic output in provinces, and they provide jobs and social security, e.g., for pensions. As a result, those companies receive local government support in the form of increased subsidies and bank loans whose effect is environmentally unsustainable. Comparable to 'crowding out effects' in welfare economics and efforts to remove subsidies, the phenomenon starts to be known in China (Jiang et al., 2017), but institutional reforms and knowledge about deep transformations of foundation industries will be needed to overcome this significant barrier.

To make the point: the downside of speed and acceleration in some areas is a lack of attention for the sectoral and regional stragglers in the CE system in China; incentives to accelerate for large majorities rather than a pioneering few are yet limited. The question therefore arises to what extent the CE policy in China is ready to cope with future structural transformations within and across industries. The policy deficit is a lack of nationwide comparative evaluations across sectors and provinces which would form the evidence base for assessing implementation gaps and could support potential enforcements in provinces. There is also an absence of litigation in the legal system (Andrews-Speed, 2022) where like-minded actors could initiate investigations and bring a case to court.

In comparison, the EU and OECD do face implementation gaps too, but have established systems of policy evaluations, surveys, and litigation combined with accountability and independent scrutiny that help to identify gaps and spur stragglers (see e.g. Domenech and Bahn-Walkowiak 2019).

Being a very large emerging economy, identifying coordination challenges in China does not come as a surprise. Our analysis is meant to stimulate further research on our topics, which could be structured along a multi-level governance framework with the transition management literature on niches, regime changes and landscape changes in mind (Schot and Kanger, 2018). Our core argument is one of success in establishing pioneers and diffusion to early adopters that contrasts with a gap towards majorities and laggards. It coincides with a focus on science and supply technology based on an excellent cooperation between universities, governments, and industry; but one also observes weaknesses in system thinking of going beyond industrial pioneers (Pesce et al., 2020) and shaping the institutional and socio-cultural underpinnings (Andrews-Speed, 2022) of dissemination, sustainable consumption, and system dynamics of transformations. A recent paper on principles for a CE evidences similar thoughts from a European perspective (Velentuur & Purnell 2022).

In order to address both implementation gaps and coordination challenges, future analysis will need to include different levels of policy making in China, the central alignment of NDRC with other ministries (see Fig 2), and consider broader market-orientated policies beyond 'market push' that would evaluate existing fees on pollution or penalties and more pro-actively internalize negative externalities throughout all levels of economy and society. The beginning of the carbon market with an emissions trading system is a step in such direction; however, issues of monitoring compliance and enforcement are pertinent. The goals of the five years 2021 – 2025 plan on recycling and waste and a circular economy need cohesion with incentives discouraging environmentally harmful behaviour, such as a landfill tax or a material input tax and regulatory measures on producer responsibility. They will also need to address distorted incentives at local and regional scales as analysed above in this chapter.

The policy learning at *meso* and micro levels could go beyond learning from success and extend to learning from failure in a transparent way, as well as building up a more effective, resilient systems of policy evaluation and learning. It is here where recent theories on deep transition (Schot and Kanger, 2018) could offer useful insights into failing socio-technical regime changes and institutional inertia that typically come through a mix of formal and informal institutions such as industrial norms and local administrative guidance. The notion of 'carbon traps' (Bernstein and Hoffmann, 2019) points at multiple incentives needed to move systems above a threshold of early adopters, with illustrations from Norway's transportation system and carbon reporting triggered through the Carbon Disclosure Project (CDP). After all, there is awareness for the complexity of shifting towards a CE in China (Pesce et al., 2020) where weaknesses on implementation gaps and coordination deficits could feed into.

With regards to CE contribution to decarbonisation in the future in China, there are still many challenges to be addressed. For instance, from the implementation perspective, there is no indicator system linking CE and decarbonisation in either eco-industrial park indicator system released by the National Mininstry of Enviromental Protection or circular economy industrial park indicator system released by the National Development and Reform Commettee (Liu et al., 2017). In addition, although the methodololy associated with calcualating decarbonisation has made significant progress in the past few years, the methodology linking CE and decarbonisation is still limited. In particular, for those CE projects associated with recycling and recovered materials which involve in secondary energy input still requires further investigation. The next subsection will address this emerging research perspective within the scope of our paper.

5.2. Implications for decarbonisation

Our analysis confirms drivers of CE achievements in China via comprehensive policies, and indicators as well as upscaling pilot projects and EIPs. It also shows that the CE policy in China has had a focus on energy efficiency in previous years and played a significant role in the reduction of carbon emissions in energy-intense industries. This is because the CE could help lowering energy-intensive raw material inputs and spur efficiency of industrial processes by improving the utilisation rate of materials and products (Peters et al., 2007; Dong et al., 2018; Zhu et al., 2019). Both resource and carbon intensity in China have been significantly reduced (Yang et al. 2019; Mi et al., 2017, 2021) and are now converging closer to ratios that can be observed in most OECD countries. Given the lack of transparent evidence-orientated policy evaluation and long-term goals in the past, however, it is almost by incidence that those policies appear aligned. It is probably fair to say that development of the CE policy has precedented climate policy in China, while the latter nowadays is a strong policy driver towards the goal of carbon neutrality set in 2020 for the year 2060. Whether or not this goal can be reached faster and at what cost is the future research perspective that should lead to a deeper alignment with CE policies.

Based on the above findings, our paper proposes to assess further decarbonisation of industries based on the strength of China's CE policy, especially addressing metals, cement, construction and buildings, chemical engineering, and the agro-food industries. Based on comparisons with industrialised countries there is still potential for further energy and resource efficiency improvements. UNEP (2019) has made the point of infrastructure development and manufacturing contributing to 65% of GHG emissions in China, if seen from a life-cycle perspective looking at end-users of energy. Our estimate is broadly in line with the Energy Transition Commission (2019) and Yang et al. (2019), with an added nuance proposing a stronger focus on the CE as a driver, which would also lower resource import dependencies in China (see section 3.2 in this paper).

Such synergies between decarbonisation of industry and the CE, however, will depend on the policy ability of tackling the challenges of implementation deficits and coordination evidenced through our paper (section 5.1), which appear in decarbonisation efforts too (Lo and Castán Broto, 2019; Andrews-Speed, 2022). A future mission for industrial strategies should embrace the CE towards net zero to address key techno-institutional issues in a transformation of key foundation industries: should investments go into a more efficient linear route such as blast furnace in steel, or into a more circular route based on electrical furnace and renewable energies; how would closing of inefficient resource-intensive sectors (e.g., cement, textiles) help to establish markets for secondary materials. The modelling work done by Nechifor et al. (2020), for instance, confirms potential future net economic gains for China as a result of shifting to secondary steel. Our paper also underlines the broader political and societal challenges of accelerating changes at the provincial and sectoral level in China. In a systems perspective, there is also a need to integrate life cycle thinking in product design stage, considering the reuse and remanufacturing of components from renewable energy technologies at the end of their lifetimes (e.g., retired wind turbines) and develop standards for a more circular product design. Systems thinking should therefore go beyond technology and industrial supply and entail a perspective on deep transitions and path dependencies at the provincial and sectoral level in China as outlined above.

The focus on place-based policy and various city-level policies (low carbon cities, circular eco-cities, sponge cities) offers another opportunity for an alignment of CE policies with decarbonisation. This is a perspective supported by Ellen MacArthur Foundation (2018) and, in broader terms, by UNEP's International Resource Panel. It would pick up recent efforts on waste management and recycling, learn from ambitious policies such as the Shanghai Master plan, and integrate industrial symbiosis, including reuse of construction and demolition waste, better water and wastewater management, agro-food, and food waste, with a supporting role for start-ups in those areas. The notion of a 'sharing economy' could also become an opportunity to address consumption patterns and strengthen EPR stewardship. In line with the above, delivering on the ambitions to transform existing parks (Fig. 4) throughout China will depend on how local challenges are addressed. To support, cities could establish data bases on building stocks and relevant material flows, ideally based on common indicators and a comprehensive data protocol. Having a system of evidence-orientated policy evaluations with an extended understanding of cost-benefit analysis and modelling tools will be useful.

The broader challenges of an alignment are in the societal dimension: China is becoming rapidly a consumption society with aspirations from an emerging middle class. Our analysis implies risks for a societal divide in China, where issues of justice, job security and access are likely to increase. Those issues are emerging topics for the CE in other parts of the world (see e.g. Kirchherr et al., 2017; Calisto Friant, 2020; Belmonte et al. 2021; Barrie et al. 2022) and deeply connected to issues of climate justice and the SDGs.

Based on our analysis, future research need to undertake more critical assessments of institutional choke points in China related to implementation gaps and coordination challenges across provinces and sectors. Applying decomposition analysis will be useful, however those socio-political considerations will require additional analysis. Doing so future research could develop novel CE pathways to model the Chinese efforts towards decarbonisation and the CE. The manifold efforts towards green finance in China also do offer options for investments and macro-economic assessments in those areas, if our analysis on indicators is translated into a taxonomy for investments.

6. Conclusions and future research

China has established strong policies towards a circular economy for almost twenty years and made considerable progress through regulatory measures and administrative guidance at the levels of provinces, cities, industrial sectors and factories. Over the years, China's CE ambitions have been rising and are now a key element in the vision of an 'ecological civilisation', and underpinned by comprehensive indicators at different levels and implementation plans in industrial strategies. Another unique feature is the progression from demonstration projects to early markets and the establishment of large-scale Eco-Industrial Parks, which is now complemented through the transformation of existing industrial parks towards a more circular industrial system. Main drivers for the doubling of resource productivity that has occurred since 1990 can be seen in a broad range of policy responses to pressing domestic environmental challenges (e.g., urban air pollution and waste, water pollution) and to a strong resource import dependence in China's role as a manufacturing hub of the world economy; consequently, the CE policy approach has been encompassing energy efficiency from early on and fits into China's policy style of promoting technological innovation and pursuing an industrial strategy. Data and other evidence suggest a policy-driven rapid and continuous increase in the uptake of a circular economy in China that has helped to decarbonise industry and other parts of the economy. This picture of the CE in China offers similarities with other CE approaches at an international level, yet it is also less focussing on the waste hierarchy compared to e.g. the EU, and policies such as public procurement play less of a role.

The overall impression, however, is mixed and the development comes at a crossraods. This article reveals weaknesses of implementation gaps and coordination challenges. It underlines gaps between (i) dissemination of pioneers into a few provinces and niche markets not yet deploying mass markets and transforming large majorities as well as (ii) coordination challenges across local governments, provinces, and industrial sectors. Not addressing those limitations would pose risks for further uptakes and any alignment with decarboniation efforts. Those risks could be aggravated by domestic societal challenges and struggle for power amongst contending elites in China (Jones and Hameiri 2021).

We therefore arrive at cautious conclusions on the prospects for a CE and a better alignment with pledges for carbon neutrality. There is both the opportunity for a leapfrogging and the risk of getting stuck in the years ahead, should those challenges remain unaddressed. In a research perspective we encourage more work on the evidence base as well as on the alignment between the CE and decarbonisation, especially for industrial and local strategies. Our analysis suggests developing new core indicators for the circular economy *and* decarbonisation driven by monitoring frameworks at different levels, with a special emphasis on assessing synergies and trade-offs with socio-economic developments at the level of provinces and cities. This could take advantage of existing data on material footprints and carbon footprints and efforts to account for the reuse rate of secondary materials; a useful direction would be a common accounting framework for publicly listed companies and a reporting on annual progress as well as on gaps between goals and today's resource use. Comparing existing data sets, e.g. by applying decomposition analysis and a range of modelling tools, will be invaluable for evidence-orientated evaluations and foresight processes towards goals and future missions. More collaborative research is encouraged on how datasets such as the EU's Community Innovation Survey and CE/RE scoreboard approaches could offer lessons and help developing joint core indicators. Another more novel angle of a collaborative learning platform will need to address lessons from deep transition research and carbon traps with emphasis on China. The latter will benefit from a comparative institutional approach, which should be able to feed into international collaborations of decarbonisation and the CE at the level of city partnerships, regional and sectoral alliances. Given the contemporary challenges of dealing with the pandemic (Ibn-Mohamed et al. 2021) and geopolitical conflicts this paper concludes with a pledge to improved research with societal impacts.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that cdocould have appeared to influence the work reported in this paper.

Acknowledgments

The paper has been developed based on a report done for the EU's Joint Research Centre. The authors wish to thank Xiaozhen XU, Beijia HUANG, Yu Zhongjue, Olga Diukanova, Nadir Preziosi for useful inputs and comments on this earlier report. We also wish to thank Yongjiang Shi, Steve Evans, and Hanmin Huang for invaluable feedback during the expert workshop, and Rainer Walz for feedback on a similar presentation done at the 25 anniversary of the EIIW Wuppertal/Frankfurt. Kate Litwinczuk has been invaluable in helping with editing. It is also supported by UKRI/EPSRC grant on Circular Metals (EP/V011804/1) and the Natural Science Foundation of China (71810107001, 72088101; 71690241; 71974129). Beijia Huang is also supported by Shanghai Pujiang Program (20PJ1412000); the Program for Professor of Special Appointment [Eastern Scholar] of Shanghai Institute of Higher Learning. Raimund Bleischwitz has moved from UCL to the Leibniz Centre for Tropical Marine Research (ZMT) in January 2022.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.resconrec.2022.106350.

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